Geophysical Investigation for Groundwater in Borokiri and Eastern-Bye Pass Areas of Port Harcourt, Nigeria.

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ABSTRACT

This study assesses the occurrence of groundwater in the Harold Wilson (Borokiri) and the Eastern Bye-Pass in Port Harcourt Metropolis, Eastern Niger Delta, Nigeria. The area lies within the Coastal Plain Sands and are very prone to the problems of saltwater intrusion. Two vertical electrical soundings (VES) were taken with the Schlumberger array with a maximum separation of 800m between the current electrodes. The vertical electrical sounding data was interpreted using RES2DINV Computer program. The results show that freshwater/saltwater interface is encountered in Harold Wilson (Borokiri) at about 30m while at Eastern Bye-Pass area it is at about 120m. This interface could fluctuate due to tidal influence on the hydrology of the area. The freshwater impoundment on the near surface aquifer is due to recharge from rainfall. Saline water decreases 94m at Harold Wilson (Borokiri) and increases about 120m at Eastern Bye-Pass. Following this, a systematic investigation of the influence of the various parameters on the extent of saline water encroachment is necessary to provide valuable information to estimate water quality pattern in the coastal areas of Port Harcourt metropolis.

(Keywords: groundwater, vertical electrical sounding, VES, resistivity saline water intrusion, freshwater)

INTRODUCTION

One of the most serious problems of water supply in the eastern Niger Delta is that of saline water intrusion into coastal aquifers. Saline water intrusion and encroachment is a situation in which there is movement of salt water into a fresh water body in an aquifer. This movement may be landward from the sea or upward from an underlying salt water body.

Saline intrusion into coastal waters has become a major concern (Bataynech, 2006), because it constitutes the most common pollutants in fresh water. In coastal areas, fresh groundwater flowing from land towards the sea comes in contact with salt and sea water. A transition zone between the fresh and salt groundwater develops due to mixing. The position of this transition zone depends on local circumstances such as distribution of hydraulic properties, climate and human interference in the form of land reclamation. This situation has been described by (Bear *et al.,* 1999; Domenico and Schwartz, 1998; Freeze and Cherry, 1979; Rushton, 2003; Walton, 1970).

Various researchers around the world have carried out geophysical survey to demonstrate the interface between fresh water and saline water. Lee and Song (2007) studied the salt water intrusion problem on the coastal area of South Korea and observed that salinity of the fresh ground water is highly associated with ground water withdrawal. Also, Barret *et al.,* (2002) successfully used Direct Current (DC) resistivity method to map perched water tables containing saline water and fresh water lenses in southern Australia. Nowroozi *et al.,* (1999) mapped the saltwater/freshwater interface in the geological setting of the eastern shore of Virginia; while Oteri (1988) confirmed the depth to the freshwater/saline water sands interface in southeast Nigeria, to vary from 77m to 947m. Recently, Adepelumi *et al.,* (2008) delineated salt water intrusion into the fresh water aquifer of Lekki Peninsula, Lagos Nigeria. Ehirim and Nwankwo (2010), Nwankwo and Emujakporue (2012) used geoelectric method for aquifer characteristics, groundwater quality evaluation and sub-soil contamination in Port Harcourt and other parts of Niger Delta region. Amadi *et al*., (2012) also investigated aquifer quality in Bonny Island using geophysical and geochemical techniques.

The expanding human influence and rapid industrialization has a drastic effect on some sections in Port Harcourt Metropolis like the Borikiri area and the Eastern Bye-Pass. Land reclamation is a common phenomenon in these areas. There is the growing need to acquire more land and build. This activity has grossly affected the freshwater/saltwater interface. The reclaimed area of Port Harcourt Peninsula was previously occupied by mangrove swamps and characterized by saline water intrusion and iron rich groundwater. The overwhelming number of failed boreholes in the area attests to this fact. It is in this background that the use of geophysical electrical resistivity sounding study is conceived to help in determining the freshwater/saltwater interface, the estimated drill depth as well as the type of geological formations (subsurface materials) to be encountered etc. With the above information, proper planning, design and maintenance of groundwater development in the area is assured. This study therefore aims to determine the geoelectric sections/ the aquiferous zones as well as delineate the freshwater/saline water interface in the area.

The Study Area

Port Harcourt is located within latitudes $6^o\ 58'$ to $7^o\ 6'$N and longitudes $4^o\ 40'$ to $4^o\ 55'$E as shown in Figure 1. It falls almost entirely within the lowland swamp forest ecological zone and is flanked in the east, west and southern limits by mangrove swamp forest (Braide *et al.*, 2004; Chindah; 2004). The area experiences heavy rainfall averaging 25000mm/annum. It rains for about eight months (March to October) during the year and even the months considered as dry months are not free from occasional rainfall (Gobo, 1990). The area has an almost flat topography and is underlain by superficial soil that consists of silty clays mixed with silty sands. The water table is less than 10m below ground surface.

Port Harcourt is located within the Quaternary alluvium tidal wetlands of the Niger Delta, with strong reversing tidal currents. The geology of the Niger Delta has been extensively documented by various research including Reyment (I965), Allen (1965), Short and Stauble (1967). The Niger Delta has an area of about 75000km^2 and the overall sedimentary sequence is dominantly composed of sand, shale and clay. The prodelta developed on the northern part of the basin during the Campanian transgression and terminated with the upper Maastrichian regression (Reyment, 1965). The formation of the modern Niger Delta is made up of marshy land masses criss-crossed by numerous rivers and creeks whose banks are made up of levees with back swamps. The formation of the land mass has been explained to be a result of sediment deposition generally associated with the River Niger and its tributaries.

The Cenozoic delta basin is said to have developed during the Cretaceous times from the RRR triple junction (Burke *et al.*, 1971). It is bounded by the basin flank to the north west, the Calabar flank to the east west and the Anambra Basin to the north. Stratigraphically, the Niger Delta is made up of three lithologic units viz; Benin, Agbada and Akata Formations (Table 1).

The Akata Formation is of marine origin, while the Agbada Formation is transitional between the upper continental Benin formation and underlying marine Akata Formation. The Benin Formation is continental and consists of coastal plain sands, deltaic plain sands, abandoned beach ridges, mangrove and freshwater swamps and alluvium, all ranging in age from Oligocene to Holocene (Table 1). Anderson (1967) showed that an ancient deltaic plain was laid down in late Pleistocene to early Holocene and occupied an area similar to the present day delta.

Brief Hydrogeology of the Area

The hydrogeology of the area is highly influenced by saline water intrusion and the presence of ferruginous sandy formation due to high oxidation condition of the near surface aquifers. The sand forms the major aquifers in the area while clay/shale forms the aquitards. The water table in the area varies with season. Generally, the water table is close to the surface, ranging from 0.6m to 1.2m below ground surface from wet season to dry season. The dominant fresh water aquifer is found within the Benin Formation which consists mostly of continental sands with clay and silt (Table 1).

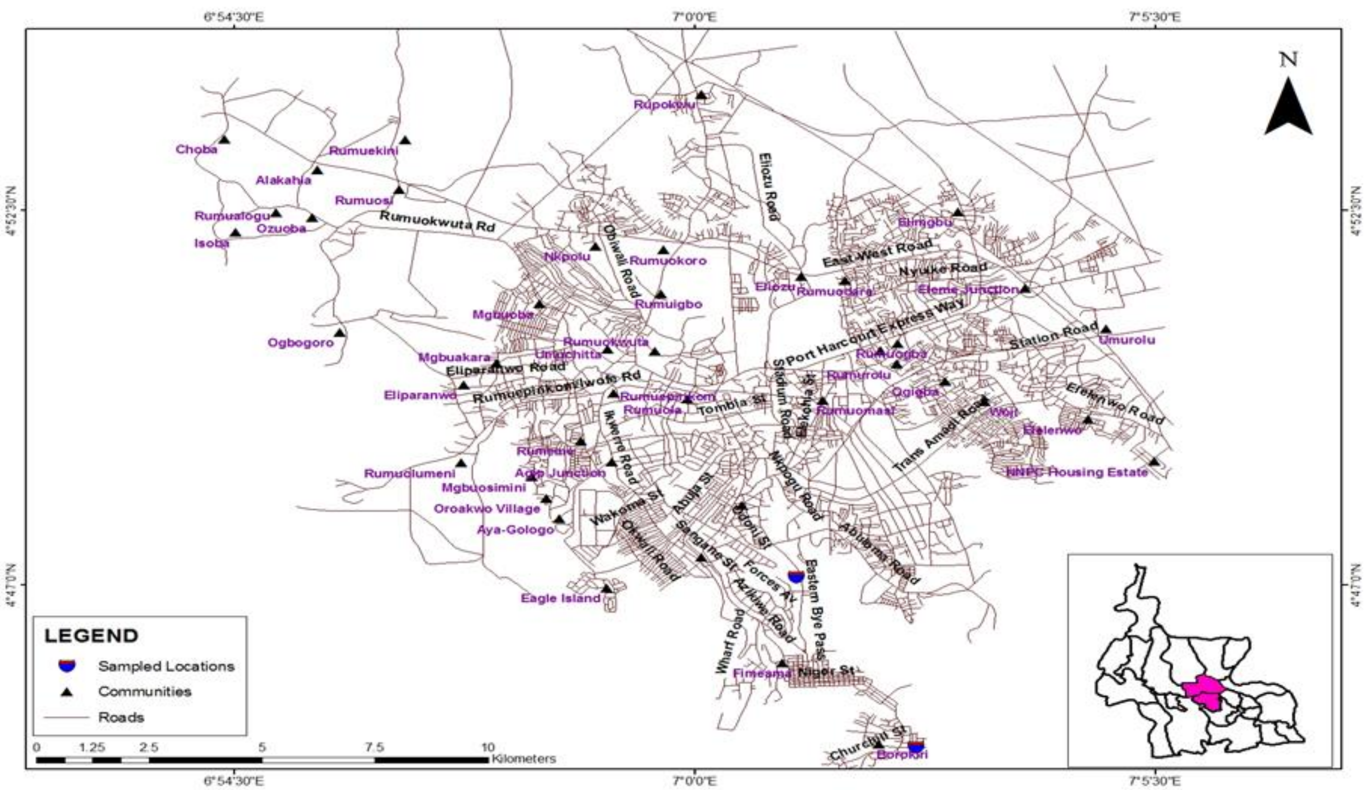

Figure1: Map of Port Harcourt Showing Study Locations,

Table 1: Geologic Units of the Niger Delta (After Short and Stauble, 1967).

Age	Geological Unit	Lithology
Quaternary	Alluvium (general) fresh water back swamp meander belt. Mangrove and salt water. Back Swamps Active/Abandoned Beach ridges Sombreiro Warri Delataic plain.	Gravel, sand, clay, silt, sand, clay, some silt gravel. Medium-fine sands. Clay and some silt.
Miocene	Benin Formation (coastal plain sand)	Coarse to medium grain sand with subordinate silt and clay lenses. Fluviatile marine
Eocene	Agbada Formation	Mixture of sand, clay and silt, fluviatile marine.
Paleocene	Akata Formation	Clay (marine shales)

These materials are believed to have been deposited in a continental fluviatile to deltaic environment. The clay units have variable thickness ranging from 1m to as much as 15m in some places. The sand and clay intercalations constitute a system of aquifers separated by aquitards given rise to a multi-aquifer system which characterize the Niger Delta (Etu-Efeotor and Odigi, 1983; Amajor, 1989).

Data on aquifer hydraulic parameters for groundwater resource evaluation are generally scanty in the study area, except those estimated by Nwankwoala, *et al*, (2008). Typical average porosity values range from 28% to 32%, while permeability values range between 5-7 Darcy.
Ngah (1990) identified three auriferous zones in the Niger Delta viz:

(i) An upper unconfined aquifer extending throughout the Benin formation with its thickness ranging between 15 m -80m, while the static water level varies between 4m and 21m.

(ii) A middle aquifer system semi-confined and consisting of thick medium to coarse grained pebbly sands with thick clay lenses. Its thickness varies between 30m to 60m.

(iii) A lower aquifer system that extends from about 220m -300m and consists of coarse grained sands and some gravels with some interlayer of clay.

Akpokodje *et al.,* (1996), however identified seven aquifers within the top (extending to 220m depth) of the sequences of the coastal depobelt.

MATERIALS AND METHODS OF STUDY

Two vertical electrical soundings (VES) were conducted in Harold Wilson (Borokiri) and Eastern Bye- Pass, Port Harcourt, Southeastern Nigeria. The VES were taken with the Schlumberger array method, with a maximum separation of 800m between the current electrodes. The equipment used for the measurement of the earth's resistivity in this study is the ABEM Terrameter (SAS) 1000 with a liquid crystal digital readout and an automatic signal averaging microprocessor. It is a method whereby consecutive readings are taken automatically and the results are averaged continuously. The continuously updated running average is presented automatically on the display. This continues until the operator is satisfied with the stability of the results. Error codes were easily interpreted with the instrument manual (ABEM, 1980) which also has detailed information on the terrameter operation.

Data Processing

2-D Resistivity Imaging Data: The measured 2D resistivity data were interpreted using the RES2DINV inversion software. This program automatically subdivides the subsurface into a number of blocks and then uses a least – squares inversion scheme to determine the appropriate resistivity values for each blocks so that the calculated apparent resistivity values agrees with the measured apparent resistivity values from the field survey. Details about the survey and interpretation methods can be found in published papers by Keller and Frischknecht, (1996), Griffiths *et al*., (1990), Griffiths and Barker, (1993), Loke & Barker, (1996) and Loke, 1999).

The results are displayed as inverted model resistivity sections versus depth of the subsurface (Figures 2 and 3). The pseudo sections show variations with depth and were visually inspected to delineate areas of anomalously high or low resistivity related to subsurface conditions.

RESULTS AND DISCUSSION

The Vertical Electrical Sounding (VES) data showing the apparent resistivity and corresponding current electrode spread are given in Table 2 for Harold Wilson (Borokiri) and Eastern Bye-Pass. The value of resistivity drops at the saline water zones while sharp increases in resistivity occur at fresh water zones for electrode spreads that determine their depth variations. Table 3 clearly shows these remarkable differences in electrode spreads between 5.0m to 7.5m, 50.0m to 275.0m, and 325.0m in Harold Wilson (Borokiri). Also, similar distinctions occur between 125.0m to 175.0m at Eastern Bye-Pass. The inverse section resistivity models obtained from the RES2DINV Software Ver. 3.48a are presented in Figures 2 and 3. The interpretations and color codes obtained were used to determine the variation in depth of the various sections of the aquiferous zones.

Table 2: Apparent Resistivity and Current Electrode Spread Data of the Study Locations.

Harold Wilson (Borokiri)		Eastern Bye-Pass	
Electrode Spread AB/2 (m)	Apparent Resistivity (Ohm-m)	Electrode Spread AB/2 (m)	Apparent Resistivity (Ohm-m)
5.00	4.86	5.00	75.24
7.50	64.03	7.50	95.40
12.50	89.97	12.50	77.98
15.00	88.39	15.00	53.65
25.00	82.50	25.00	46.36
45.00	80.95	45.00	37.21
50.00	64.33	50.00	35.78
70.00	53.66	70.00	43.90
90.00	35.36	90.00	59.77
125.00	32.54	125.00	52.28
175.00	11.73	175.00	2305.98
225.00	8.28	225.00	96.29
275.00	24.78	275.00	164.35
325.00	1301.95	325.00	114.70
375.00	222.15	375.00	138.69
425.00	279.78	425.00	120.42

Table 3: Summary of Varying Layer Thicknesses of the Study Areas.

Layers	Harold Wilson (Borokiri)		Eastern By-Pass	
	Thickness (m)	Apparent Resistivity (Ωm)	Thickness (m)	Apparent Resistivity (Ωm)
Sandy Zone	-	-	1.0 - 5.2	124.0
Sandy clay/Clay Zone	1.0 – 8.0	8.3	5.2 – 2.5	50.6
Fresh water mould	8.0 – 25.0	78.4	-	-
Main Aquifer	94.0 – 200	78.4	25.0 – 120.0	20.6
Saline Zone	27.0 – 94.0	0.4	120.0-200.0	1.4

For geophysical methods to supply hydrogeological useful answers there must be contrast in the physical properties of the subsurface layers. These contrasts must be related to or affect the physical measurement that are made such as the electrical property as applied in this study. The greater the contrast, the sharper the measured responses and the more accurate the results would be.

Where both water chemistry and porosity vary, interpretation of lithology from bulk resistivity value is difficult. This is so in the study area where the results of the vertical electric sounding (VES) show geoelectric layers that vary in thickness and apparent resistivity (Table 3). These layers consist of upper top soil and intervening layers of sand with silt and clay intercalations. The inverse model resistivity sections in the two study areas show a variation in their overall trend as shown in Figures 2 and 3.

The reason for this could be attributed to the mixed environment nature of the area which is the mangrove swamp sediments overlain by fresh water sand deposits. Variations in the layers are based on the resistivity values obtained in this study relative to resistivity values for natural waters and rocks as obtained in Tables 3.

Results from this study have proven similar studies within the Niger Delta showing that, geoelectric soundings have been used to successfully delineate aquifers and determine freshwater/saltwater interface.

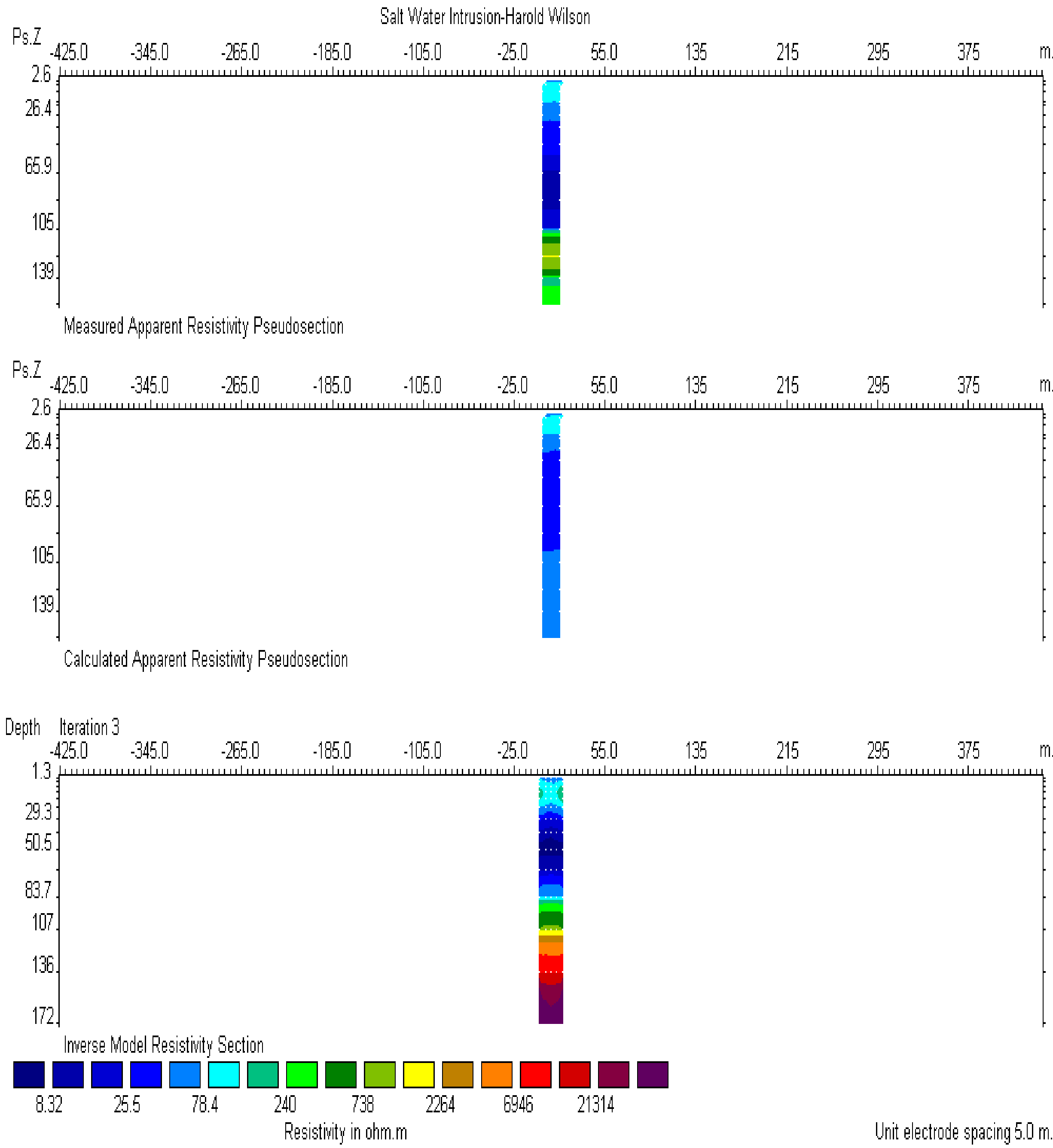

Figure 2: Inverse Model Resistivity for Harold Wilson (Borikiri).

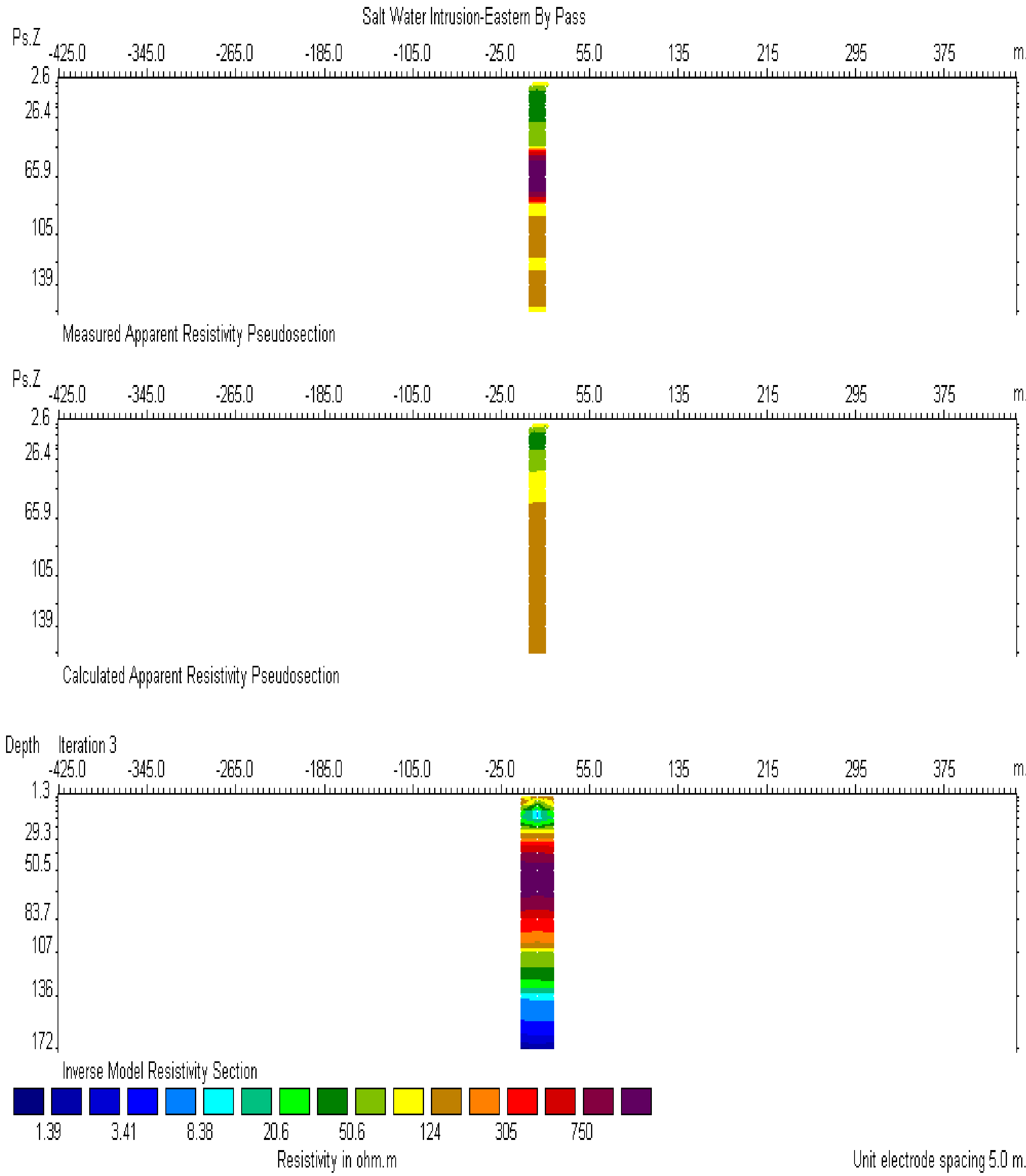

Figure 3: Inverse Model Resistivity Section for Eastern Bye-Pass.

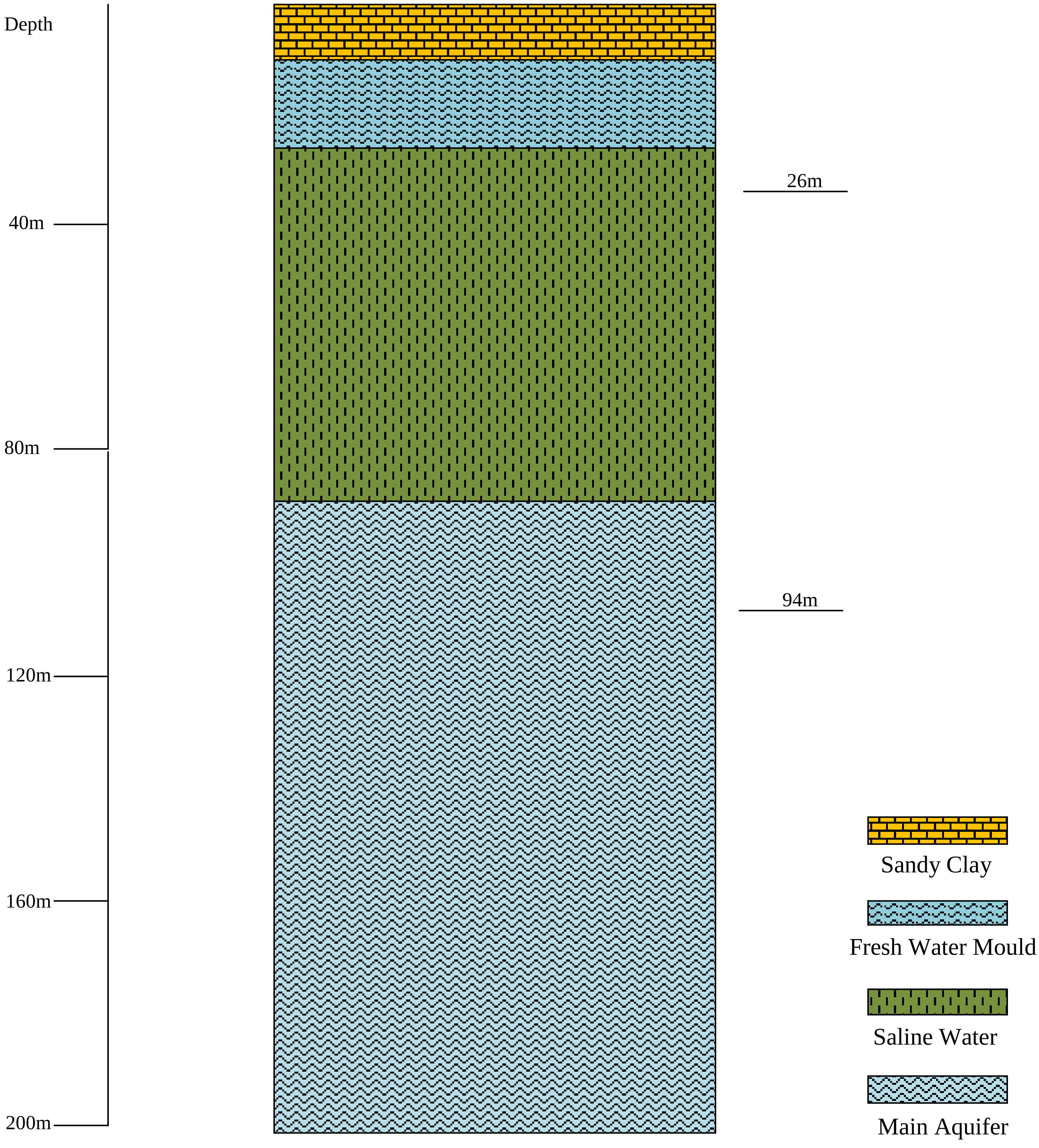

Figure 4: Geo-electric Log for Harold Wilson (Borikiri).

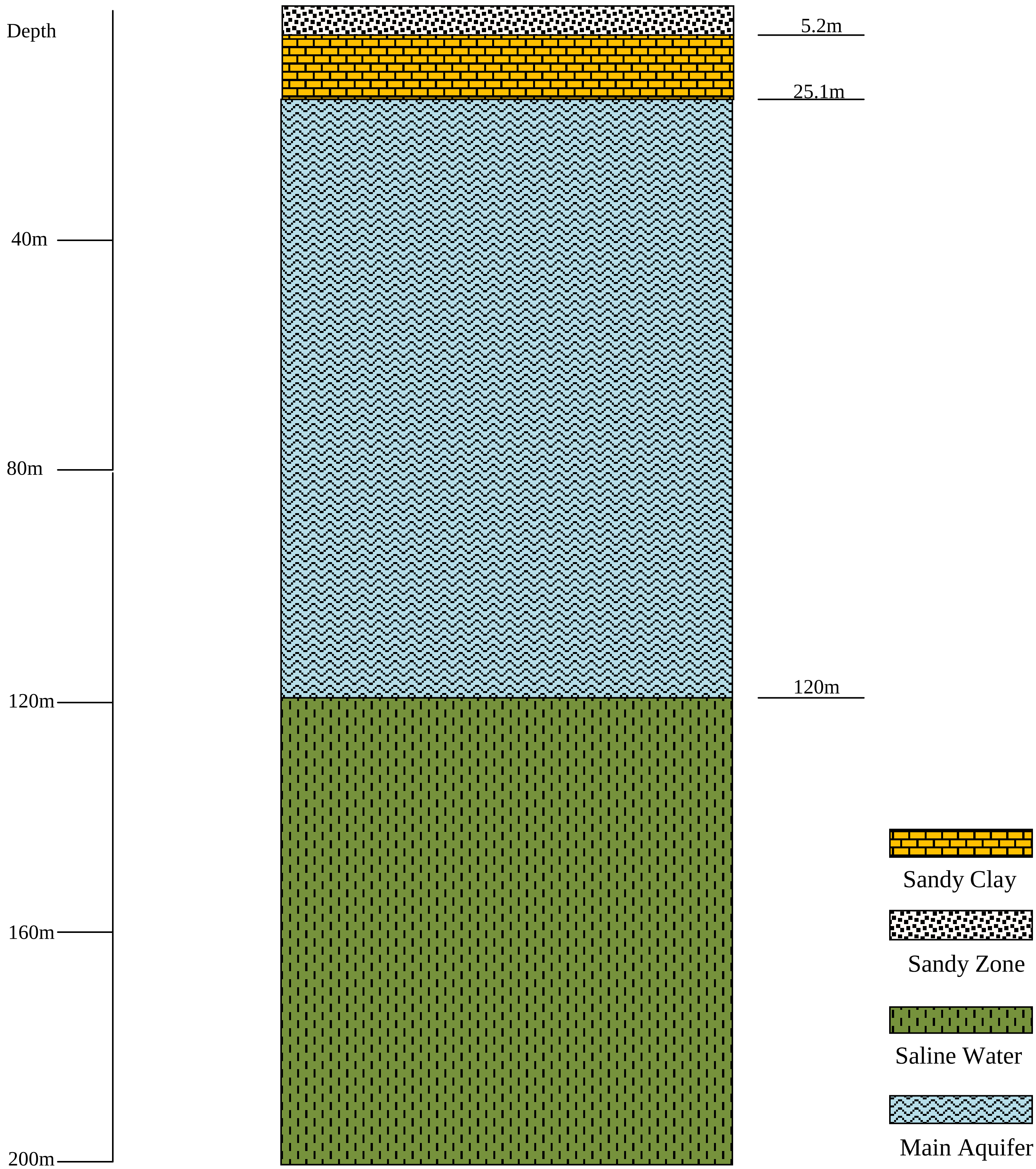

Figure 5: Geo-electric Log for Eastern Bye-Pass.

It has also confirmed that the water table in coastal areas of parts of the Niger Delta varies from 2.0m to 8.0m as seen at Harold Wilson (Borokiri); and that coastal aquifers are invaded by saltwater in which the depths which are dependent on the distance of the aquifer from the seacoast (Mbipon and Archibong, 1989; Oteri 1990).

CONCLUSION

The Vertical Electrical Sounding (VES) technique has been found to be a useful tool in the investigation of groundwater resources. Information obtained from the application of VES in areas in Port Harcourt will lead to a better understanding of the geology/hydrology of the area. The thickness of the fresh water lens has been inferred from the study. Water resources could sensibly be developed by mapping the fresh water and fresh/saltwater interface to meet long term needs of the area.

There is need to avoid long periods of over abstraction as this could result to saltwater intrusion into the freshwater aquifer due to reversal of the hydraulic gradient of groundwater. When this happens, the saltwater/freshwater interface moves towards a fresh water zone thereby extending the zone of saline contamination. Intense geophysical study of the area could help define high yielding shallow freshwater aquifer systems, which when all hydraulic parameters are well known could be managed to exclude saltwater intrusion and sustain the water needs of the area. These would provide the hydro-geologists a valuable guide in choosing where to screen, type of screen, gravel pack, casing interval and where to grout and backfill boreholes.

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SUGGESTED CITATION

Nwankwoala, H.O. and M.L. Omunguye. 2013. "Geophysical Investigation for Groundwater in Borokiri and Eastern-Bye Pass Areas of Port Harcourt, Nigeria". *Pacific Journal of Science and Technology*. 14(1):524-535.

Pacific Journal of Science and Technology